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(71) Applicant *(for all designated States except US)*: STMICROELECTRONICS ASIA PACIFIC PTE LTD [SG/SG]; 28 Ang Mo Kio Industrial Park 2, Singapore 569508 (SG).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: PAI, Pratima [IN/SG]; Block 414 Ang Mo Kio Avenue 10, #03–933, Singapore 560414 (SG). DA COSTA, Godfrey [IN/SG]; Block 414 Ang Mo Kio Avenue 10, #03–933, Singapore 560414 (SG).

(74) Agent: DONALDSON & BURKINSHAW; P.O. Box 3667, Singapore 905667 (SG).

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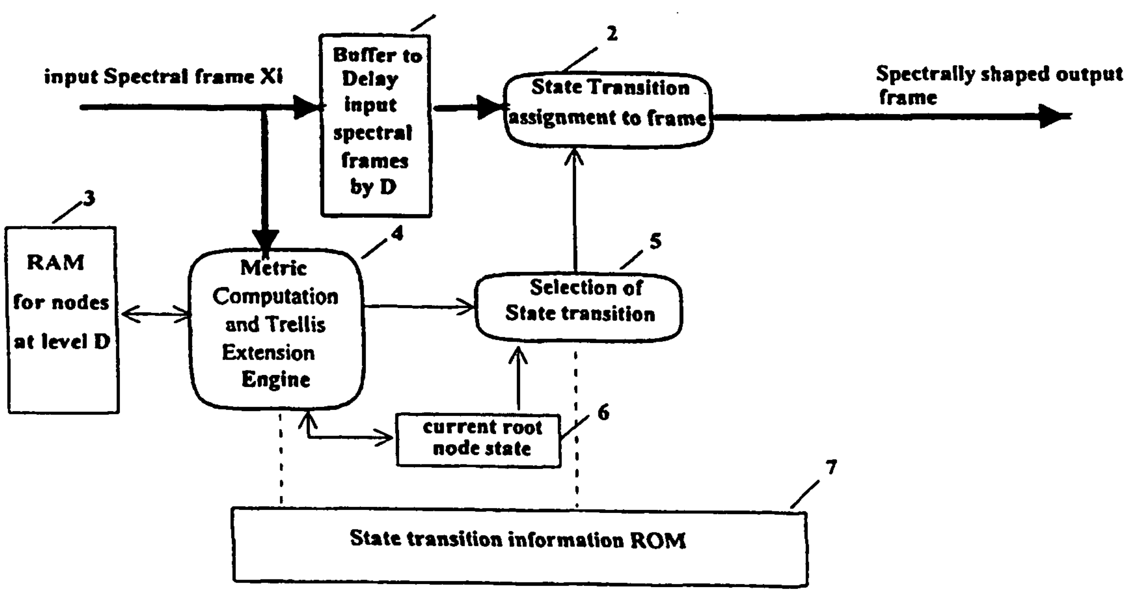

(57) Abstract

Methods and apparatus for efficient implementation of a frame based trellis spectral shaping with a variable look–ahead depth are provided. Conventionally, a look–ahead depth results in a start–up phase followed steady state phase, resulting in increased complexity. Uniformity in the implementation for variable look–ahead delays is possible by allowing a predetermined path in the trellis during the start–up phase. The preferred method of implementation of the trellis based spectral shaping reduces memory and computational requirements.

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METHODS OF EFFICIENT IMPLEMENTATION OF TRELLIS BASED SPECTRAL SHAPING WITH LOOKAHEAD

Field of the Invention

This invention relates to systems an methods for spectral shaping of signals in communications systems, and is particularly applicable to data communication equipment like a modem.

Background of the Invention

In digital communications it is sometimes desirable to avoid transmission at certain frequencies in the transmission spectrum. It is usually necessary to do so in order to avoid undesirable distortion which might result if communications signals use certain frequency components. The presence of such distortion can lead to unnecessary performance degradation.

To avoid transmission at the undesirable frequencies in the spectrum it is necessary to shape the transmission spectrum of the transmitted signals accordingly. The principles of spectral shaping are conveniently described, for example, in United States patent 5,818,879, entitled "Device, System and Method for Spectrally Shaping Transmitted Data Signals". Previously proposed schemes for spectral shaping achieve the desired result by the use of redundancy. One such scheme is the trellis based spectral shaping which has been proposed for the V.90 standard to be ratified by the ITU-T. This scheme uses a convolutional code with two states and provides significant gain.

Summary of the Invention

A straightforward M-ary tree implementation conventionally requires a start-up phase and a steady-state phase, increasing the complexity. In one aspect of the present invention pre-

determined state transitions according to a valid trellis path are assumed during the start-up phase. The performance penalty for small look-ahead depth is insignificant and deviation if present is for a very short duration.

In accordance with the present invention, there is provided a method of coding digital data for transmission according to a trellis coding system having a predetermined number of states and a predetermined number of state transitions from each state, wherein the data is arranged in a series of frames and a state is associated with each frame to determine a coding strategy for the frame, comprising the steps of:

selecting a look-ahead depth (D) representing a number of data frames;

assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path;

sequentially fetching subsequent data frames in the series and determining respective states therefor based on a path metric for state transitions computed over the number of frames represented by the look-ahead depth; and

coding the data frames for transmission according to the coding strategies corresponding to the states assigned or determined for the frames, wherein the series of data frames are coded for a shaped spectrum upon transmission thereof.

The present invention also provides a data encoder for generating spectrally shaped coded data according to a trellis coding system for transmission using a modem or the like, wherein the data is arranged in a series of data frames from a data source and a trellis state is associated with each data frame such that a coding scheme for each frame may be determined on the basis of transitions of states for frames over a selected look-ahead depth (D), comprising:

a buffer memory coupled to the data source for buffering data frames in the series of data frames by the selected look-ahead depth (D);

a metric computation and trellis extension engine coupled to sequentially receive said data frames from the data source and determine node information in a plurality of nodes for each said frame representing possible states, state transitions from a preceding frame and path

metrics for the state transitions;

a current state storage coupled to the metric computation and trellis extension engine for storing the state of a current frame in the series of data frames;

a node memory coupled to the metric computation and trellis extension engine for storing said node information for nodes of a frame succeeding the current frame by the look-ahead depth;

a coding scheme memory for storing a correlation between state transitions and respective coding schemes; and

a processing circuit coupled to the coding scheme memory and metric computation and trellis extension engine for applying a selected coding scheme to a data frame to generate spectrally shaped coded data;

wherein said metric computation and trellis extension engine determines the selected coding scheme for the current frame according to the state stored in the current state storage and a node for the frame succeeding the current frame by the look-ahead depth which is selected on the basis of the path metric for the node.

In the preferred for of the present invention, the start-up phase and the steady state are unified. The trellis shaper chooses a predetermined valid trellis path during the start-up phase irrespective of the criterion for selection of the sub-tree. Once in the steady state, it uses the selection criterion to select the state transition.

The trellis shaping function of the preferred embodiment is implemented with a linear structure that requires memory for only the nodes at level D of the binary tree. In the steady state phase, for each input spectral shaper frame X_{i+D} the preferred embodiment computes the path metric associated with each of the M^{D+1} paths. The node at level D+1 which satisfies the selection criterion is then chosen as the best path. The state transition from the current root node and the subsequent root node is determined by the current trellis state and the best path.

The preferred implementation provides a significant reduction in computation and memory

requirements, and the performance penalty as a result is insignificant.

Brief Description of the Drawings

The invention is described in greater detail hereinbelow, by way of example only, through description of preferred embodiments and with reference to the accompanying drawings, wherein:

Figure 1 is an exemplary state diagram of a two state trellis spectral shaping code;

Figure 2 illustrates a steady state binary tree diagram for a two state trellis based spectral shaping code with look-ahead depth of 3;

Figure 3 is an exemplary diagram of design of a trellis based spectral shaper; and

Figure 4 is a block diagram of an encoder for use in a modem or the like in which embodiments of the present invention may be implemented.

Detailed Description of the Preferred Embodiments

By way of background, Figure 4 is a block diagram which illustrates an overview of an encoder for use in a digital modem or the like, and represents one data frame. In the following description, data frames in the digital modem have a six-symbol structure. Each symbol position within the data frame is called a data frame interval and is indicated by a cyclic time index, i = 0, ..., 5. Frame synchronisation between the digital modem transmitter and an analogue modem receiver is established during training procedures.

Mapping parameters for the encoder, established during training or rate renegotiation procedures, are:

(i) six PCM code sets, one for each data frame interval 0 to 5, where data frame interval i has M_i members;

(ii) K, the number of modulus encoder input data bits per data frame;

(iii) S_r, the number of PCM code sign bits per data frame used as redundancy for spectral shaping; and

(iv) S, the number of input data bits for the spectral shaping scheme, where $S + S_r = 6$, define

the six PCM code sign bits according to a sign assignment procedure.

The encoder 10 illustrated in Figure 4 includes a bit parser 12 which receives D (equal to S + K) serial input data bits d_0 to d_{D-1}, and is coupled to a modulus encoder 14 and a spectral shaper 22. The input data bits d_0 to d_{D-1} (where d_0 is first in time) are parsed into S sign input bits and K modulus encoder bits. The data bits d_0 to d_{S-1} form s_0 to s_{S-1}, and d_S to d_{D-1} form b_0 to b_{K-1}.

K bits enter the modulus encoder 14. Additionally, there are six independent mapping moduli, M_0 to M_5, which are the number of members in the PCM code sets defined for data frame interval 0 to data frame interval 5, respectively. The modulus encoder 14 converts K bits into six numbers, K_0 to K_5, using the following algorithm which is specified in the aforementioned proposed standard:

1. Represent the incoming K bits as an integer, R_0:

$$R_0 = b_0 + b_1{}^*2^1 + b_2{}^*2^2 + \ldots + b_{K-1}{}^*2^{K-1}$$

2. Divide R_0 by M_0. The remainder of this division gives K_0, the quotient becomes R_1 for use in the calculation for the next data frame interval. Continue for the remaining give data frame intervals. This gives K_0 to K_5 as:

$$K_i = R_i \text{ modulo } M_i, \text{ where } 0 \leq K_i < M_i;\ R_{i+1} = (R_i - K_i) / M_i$$

3. The numbers K_0, ..., K_5 are the output of the modulus encoder, where K_0 corresponds to data frame interval 0 and K_5 corresponds to data frame interval 5.

The modulus encoder 14 is coupled to six independent mappers 16 associated with the six data frame intervals. Each mapper is a tabulation of M_i PCM codes (corresponding to positive analogue values) that make up the constellation points of data from interval i. The PCM codes to be used in each data frame interval are specified by the analogue modem during training procedures. Each mapper 16 receives the quantities K_i from the modulus encoder 14 and forms Ucode values U_i by choosing the constellation point labelled by K_i.

Spectral shaping carried out according to the aforementioned standard by the spectral shaper 22 only affects the sign bits of transmitted PCM symbols. In every data frame of 6 symbol intervals, S_r sign bits are used as redundancy for spectral shaping while the remaining S sign bits carry user information. The redundancy, S_r is specified by the analogue modem during training procedures and can be 0, 1, 2, or 3. When $S_r = 0$, spectral shaping is disabled.

The spectral shaper operates on a spectral shaper frame basis. For the cases $S_r = 2$ and $S_r = 3$, there are multiple shaper frames per six-symbol data frame. Spectral shaper operation for each shaper frame within a data frame (herein referred to as a shaping frame j) is identical except that they affect different data frame PCM sign bits. In particular, the spectral shaper modifies initial sign bits to corresponding PCM code sign bits ($\$_0$, $\$_1$ ...) without violating the constraint described below, so as to optimize a spectral metric.

The constraint of the spectral shaper can be described by way of a 2-state trellis diagram, such as that shown in Figure 1. In a given spectral shaping frame i, the spectral shaper modifies the initial sign sequence according to one of the following four sign inversion rules:

Rule A: Do nothing;

Rule B: invert all sign bits in the spectral shaping frame;

Rule C: Invert odd-numbered sign bits in the spectral shaping frame;

Rule D: Invert even-numbered sign bits in the spectral shaping frame.

The trellis diagram describes the sequence of sign inversion rules that are allowable. For example, when the spectral shaper is in state S_0 at the beginning of frame i, only rules A and B are allowable in that frame. The current state together with the sign inversion rule selected for the frame determine the next state according to the trellis diagram.

A look-ahead depth parameter D may be an integer between 0 and 3, for example, selected by the analogue receiving modem during training procedures. Look-ahead depths of 0 and 1 are mandatory in the digital modem according to the aforementioned standard, whereas look-ahead depths of 2 and 3 are optional. To select the sign inversion rule for the i^{th} spectral shaping frame,

the spectral shaper uses the PCM symbol magnitudes produced by the mapper 16 for spectral shaping frames i, i+1, ..., i+D. The spectral metric that would result from each of the allowable sequences of sign inversion rules for frames i through i+D, starting from the current state, is then computed. Based on those computations, the spectral shaper then selects the sign inversion rule for frame i that minimizes the spectral metric, which is defined as the sum of the squares of the RFS up to and including the final symbol of spectral shaping frame i+D. The selection thus determines the next state of the system. The spectral shaper then sets the PCM code signs for shaping frame according to the selected sign inversion rule.

A trellis based spectral shaping scheme in an embodiment of the present invention uses a trellis code with N states and M state transitions from each state (M, N positive integers). Performance gain is achieved by using larger redundancy and increasing the look-ahead depth. Trellis based spectral shaping is usually implemented using M-ary trees. The information to be spectrally shaped is assumed to be framed and is hereafter referred to as the spectral shaper frame. The size of the spectral shaper frame varies to accommodate additionally redundancy bits. The spectral frame size and the look-ahead depth D being variables, the complexity of implementation of the spectral shaping technique increases. An implementation scheme which deals with all the cases uniformly is desired to make it computationally efficient. The memory requirements for the scheme should also be kept as small as possible.

The trellis state diagram for the two state trellis is as shown in Figure 1, having two states S_0 and S_1. The state transitions are labelled a, b, c and d and associated with state transitions $S_0 \rightarrow S_0$, $S_0 \rightarrow S_1$, $S_1 \rightarrow S_0$ and $S_1 \rightarrow S_1$, respectively. The state transition in a trellis depends on the current state and a selection criteria for the state transition. Only certain sequence of state-transitions are allowed, and they constitute a valid path. These valid paths are defined by the trellis code. The selection of the state transition for a spectral shaper frame X_i and using a look-ahead depth of D requires spectral shaper frames $X_i, X_{i+1}, \ldots, X_{i+D}$. Therefore, on start-up the binary tree should be filled up to level D to commence state transition assignment. This phase is called the start-up phase. The first state in the trellis is

pre-defined and the first state transition thus emanates from that predetermined state. The start-up phase lasts for D spectral shaper frames, and thereafter the system enters into a steady state phase. The state transition selected is one of the two possible state transitions from the current state S_i and the criterion for selection is the metric computed for spectral shaper frame X_{i+D}.

For the case of N=2, and M=2, a complete binary tree T can be constructed with the root node being the current state S_i. The maximum level of the tree is D+1 where D is the look-ahead depth. There will be a total of 2^{D+1} paths and 2^{D+2}-1 nodes in the binary tree. With every input spectral shaper frame X_{i+D}, a new root node is selected and the trellis is extended at level D. Each node at level D has two state transitions emanating from it resulting in a total of $p=2^{D+1}$ nodes at level D+1. The metrics corresponding to each of the p state transitions are computed. These are the branch metrics. The path metrics for the p paths are updated by adding the branch metrics to the accumulated path metrics of nodes at level D. The node at level D+1 which gives the lowest path metric according to a criterion is selected as the best node. The tree is then traversed backwards from selected node to reach the root node. The state transition assignment for the spectral shaper frame X_i is selected to be either the left or right subtree of the root node R_i according to whether the selected node is a left of the left or right subtree of this root. The tree is then updated with the root R_{i+1} being the node connected to R_i. The leaves of the new tree so formed are at level D+1. This procedure is continued for every new input spectral shaper frame. The memory requirements for this implementation is $O(2^{D+2} - 1)$.

The procedure can be generalised for any trellis code with N states and M state transitions from each state. The tree thus formed will be M-ary and complete. The memory requirements for a lookahead depth D spectral shaper code in this case will be $O(\frac{M^{D+2}-1}{M-1})$.

Figure 3 is a block diagram of processing apparatus for implementing the spectral shaping

scheme of the preferred embodiment of the present invention. The processing apparatus 9 receives spectral frames X_i as input, and outputs spectrally shaped output frames. The input spectral frames are provided to a delay buffer 1, which delays the input spectral frames by the look-ahead depth D before passing them to a state transition application circuit 2 which applies the spectral shaping and outputs the spectrally shaped output frames. The spectral shaping which is applied by the state transition circuit 2 is determined by spectral shaping processing circuitry on the basis of the input spectral frames over the look-ahead depth. The spectral shaping processing circuitry includes a metric computation and trellis extension engine 3, a node memory RAM 3, a current root node state storage 6, a state transition information ROM 7, and a state transition selector 5. The operation of the processing apparatus 9 is described in greater detail hereinbelow.

The input spectral frame buffer 1 is zeroed at reset. The decision on the state assignment for the first spectral frame is taken only after D spectral frames are input to the delay buffer 1. However all the operations in the preferred embodiment of the present invention are performed as in steady state. The metric computation and trellis extension engine 4 performs operation as in steady state during the start-up phase (e.g. during the first D spectral frames). This is achieved by assuming that a specific valid trellis path is taken irrespective of the metric computations. This is necessary because the first state in the trellis is predetermined. This predetermined path is used for updating of the next root node state 6 and subsequent updating of the nodes table in node RAM 3. This procedure is carried on till D-1 frames are input to the trellis shaper. The procedure employed during the start-up phase is similar in every respect to that of the steady-state phase except that the root node state 6 is predetermined in the start-up phase.

The D^{th} input spectral frame is stored in the input spectral frame buffer 1. The same frame is input to the metric computation and trellis extension engine 4. The nodes at level D are extended with all possible state transitions emanating from them. The state transition information is read from the state transition information ROM 7. The metrics for all nodes

are computed and accumulated to get the path metrics for all possible paths starting from the root node. The path metrics so computed for all the paths emanating from nodes at level D are compared and the one which satisfies the path selection criterion is chosen as the best node at level D+1. The subtree which contains the best node is then chosen and the node RAM 3 is updated with the nodes at level D in the subtree. The current root node state 6 of the trellis is also updated.

The current root node state 6 and the best node at level D+1 computed by the metric computation and trellis extension engine 4 is used to select the state transition between the current root node and the next current root node. The state transition selector 5 receives the state transition information from ROM 7. The state transition information is then applied to the D^{th} previous input spectral frame by the state transition application circuit 2. The resultant frame is the spectrally shaped frame.

As mentioned above, the metric computation and trellis extension engine 4 computes the branch metric for all possible state transitions emanating from nodes at level D. The path metrics starting from the root nodes to all the nodes at level D+1 are accumulated. There is sufficient scratch memory in the metric computation and trellis extension engine 4 and node RAM 3 to hold the temporary node memory for level D+1. After searching for the best path which satisfies the preferred criterion, the sub-tree which contains the best node at level D+1 is stored in node memory 4. The node memory 4 is a linear array of all nodes at level D. For a two state trellis code with two state transitions from each node, Figure 2 illustrates the steady state tree structure with level D+1 for a look-ahead depth of D=2. The allocation for the nodes in node memory 4 is N1, N2, N3, ..., N8 and in that order. This structure is very efficient because when the best node is computed, it is very easy to locate the subtree (left or right for the binary tree case) to which the best node is connected to. This provides the state transition and the root node for the next iteration.

An example of a trellis based spectral shaping code is illustrated in Figure 1 for the case of

M=2, and N=2, and Figure 2 is the corresponding steady state representation of the binary tree with look-ahead depth of D=2. During the start-up phase, the trellis state is predetermined to be state S_0, for example. The first D-1 spectral shaper frames X_1, X_2, ..., X_{D-1}, are stored in the input frame buffer 1. Each frame is fed to the metric computation and trellis extension engine 4, where the branch and path metrics for all the paths are computed as if in the steady state phase. The node memory 3 is updated such that a fixed trellis path starting from state S_0 is followed irrespective of the path metrics and the selection criterion. This is done because complete node information for the whole path is not available until the spectral shaper frame X_D is provided to the metric computation and trellis extension engine 4. The current root node state is also predetermined, according to the selected valid trellis path starting from the predetermined initial state S_0.

When the spectral shaper frame X_D is provided to the input buffer 1 and the metric computation and trellis extension engine 4, the steady state phase is reached. The trellis is then extended to level D+1. The branch metrics for all states emanating from nodes at level D are computed and accumulated with the previous path metrics to obtain the total path metrics. For the M=2, N=2 case, for any lookahead depth $D \geq 1$, the state transitions at level D+1 will be the state transition a, b, c, d,....a, b, c, d, and it is not necessary to store this information in state transition information ROM 7. A total of 2^{D+1} path metrics are computed for every new input at level D+1. The paths are numbered 1, 2, 3, 4 ....2^{D+1} and are stored linearly in memory. the path which satisfies the spectral shaping criterion will be selected as the best path, and the selected path number decides whether the best path is in the left or right sub-tree. If best path number is less than or equal to 2^D, then the left subtree is selected, else the right subtree is selected. Knowing the current state and the best node, the current root node state 6 is updated. The metric computation and trellis extension engine 4 updates the node memory 3 with the selected subtree. The state transition for the spectral frame is loaded from state transition ROM 7 using the current root node state. It is then applied to the Dth previous frame to produce the spectrally shaped frame by the state transition application circuit 2. The above described procedure is followed for every

successive spectral shaper frame.

The preferred embodiment of the present invention simplifies the design of the trellis based spectral shaper for variable look-ahead depth and variable spectral frame size. Treating the start-up phase and the steady phase uniformly reduces complexity. It also allows simple linear structures for storage of node information. This results in the effect of reducing design complexity of the trellis based spectral shaper by reducing computational and memory requirements.

As will be appreciated by those skilled in the art from the foregoing description, operating directly in the steady state allows usage of a structure which is not a M-ary tree. The RAM requirements for storing the node information in node memory 3 is $O(M^D)$. The M-ary tree traversing is also circumvented by using the state of the root node for determining the state transition association with the current spectral shaper frame X_i. This enables a significant reduction in memory and computational requirements.

The foregoing detailed description of embodiments of the present invention has been presented by way of example only, and is not intended to be considered limiting to the invention as defined in the appended claims.

Claims:

1. A method of coding digital data for transmission according to a trellis coding system having a predetermined number of (N) states and a predetermined number of (M) state transitions from each state, wherein the data is arranged in a series of frames and a state is associated with each frame to determine a coding strategy for the frame, comprising the steps of:

selecting a look-ahead depth (D) representing a number of data frames;

assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path;

sequentially fetching subsequent data frames in the series and determining respective states therefor based on a path metric for state transitions computed over the number of frames represented by the look-ahead depth; and

coding the data frames for transmission according to the coding strategies corresponding to the states assigned or determined for the frames, wherein the series of data frames are coded for a shaped spectrum upon transmission thereof.

2. A method as claimed in claim 1, wherein fetched data frames are buffered over said look-ahead depth from a current frame X_i to a look-ahead depth frame X_{i+D}.

3. A method as claimed in claim 2, wherein node information for nodes representing possible state transitions at the look-ahead depth are stored in a node memory in an ordered array, and wherein the coding strategy for the current data frame X_i is determined on the basis of a node selected at the look-ahead depth according to said path metric.

4. A method as claimed in claim 3, wherein the node information in said node memory is replaced for each new data frame in the series.

5. A method as claimed in claim 3, wherein the coding strategy for the current data frame X_i is determined according to a state transition from the state associated with said current frame which is determined by a comparison of the position of the node selected at the look-ahead depth with at least one predetermined threshold.

6. A data encoder for generating spectrally shaped coded data according to a trellis coding system for transmission using a modem or the like, wherein the data is arranged in a series of data frames from a data source and a trellis state is associated with each data frame such that a coding scheme for each frame may be determined on the basis of transitions of states for frames over a selected look-ahead depth (D), comprising:

a buffer memory coupled to the data source for buffering data frames in the series of data frames by the selected look-ahead depth (D);

a metric computation and trellis extension engine coupled to sequentially receive said data frames from the data source and determine node information in a plurality of nodes for each said frame representing possible states, state transitions from a preceding frame and path metrics for the state transitions;

a current state storage coupled to the metric computation and trellis extension engine for storing the state of a current frame in the series of data frames;

a node memory coupled to the metric computation and trellis extension engine for storing said node information for nodes of a frame succeeding the current frame by the look-ahead depth;

a coding scheme memory for storing a correlation between state transitions and respective coding schemes; and

a processing circuit coupled to the coding scheme memory and metric computation and trellis extension engine for applying a selected coding scheme to a data frame to generate spectrally shaped coded data;

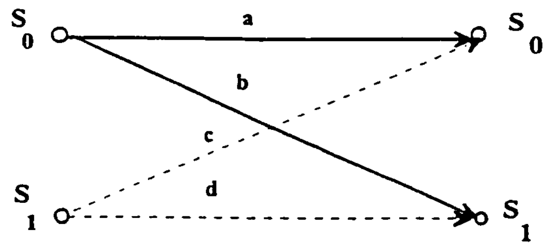
wherein said metric computation and trellis extension engine determines the selected coding scheme for the current frame according to the state stored in the current state storage and a node for the frame succeeding the current frame by the look-ahead depth which is

selected on the basis of the path metric for the node.

7. An encoder as claimed in claim 6 wherein, for the first frames within the look-ahead depth of the series of data frames, states and state transitions are assigned according to a predetermined valid trellis path.

8. An encoder as claimed in claim 6 or 7, wherein for each said data frame received by the metric computation and trellis extension engine the node information in the node memory is replaced with new node information representing the received data frame and the possible state transitions from the preceding data frame.

9. An encoder as claimed in claim 8, wherein the node information for the nodes is stored in linear array in said node memory, and wherein the coding scheme for the current frame is determined according to the position of the selected node within the node memory linear array.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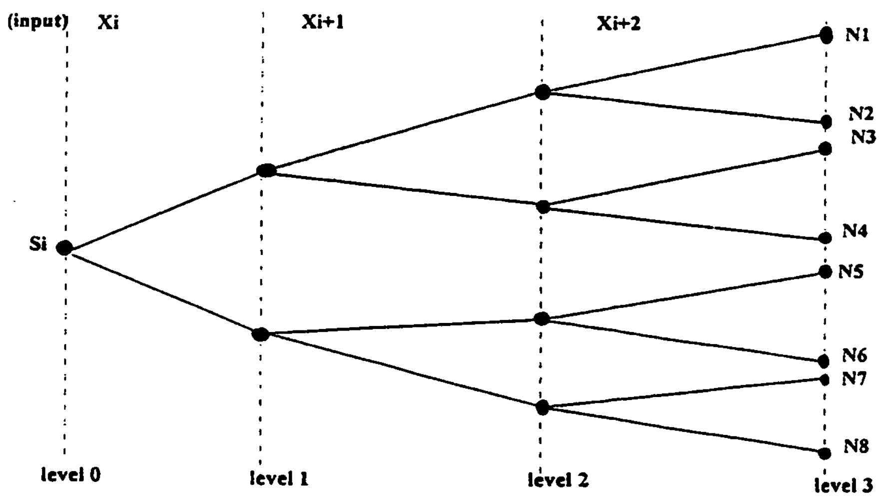
a
S 0
b
c
S 1
d
S 1

Fig(1)


(input)
Xi
Xi+1
Xi+2
Si
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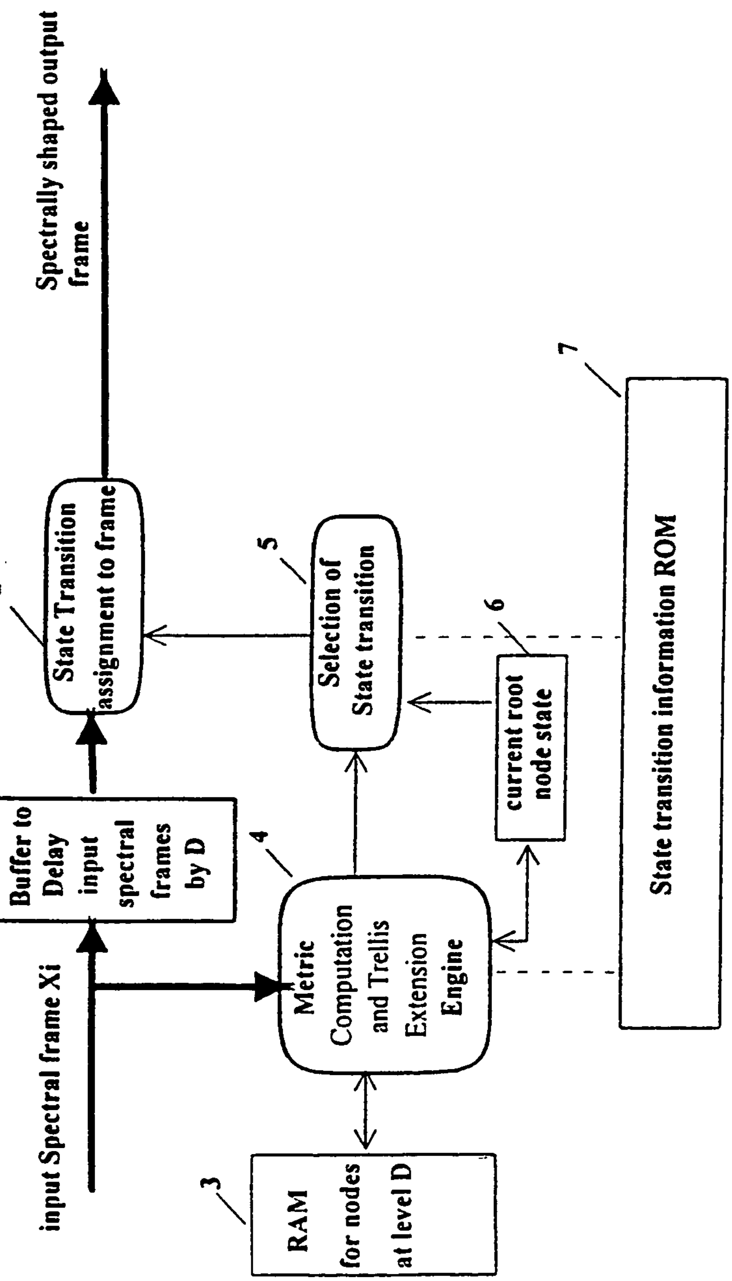
N2
N3
N4
N5
N6
N7
N8
level 0
level 1
level 2
level 3

Fig(2)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1
Buffer to Delay input spectral frames by D
2
State Transition assignment to frame
Spectrally shaped output frame
3
RAM for nodes at level D
4
Metric Computation and Trellis Extension Engine
5
Selection of State transition
6
current root node state
7
State transition information ROM

Fig(3)

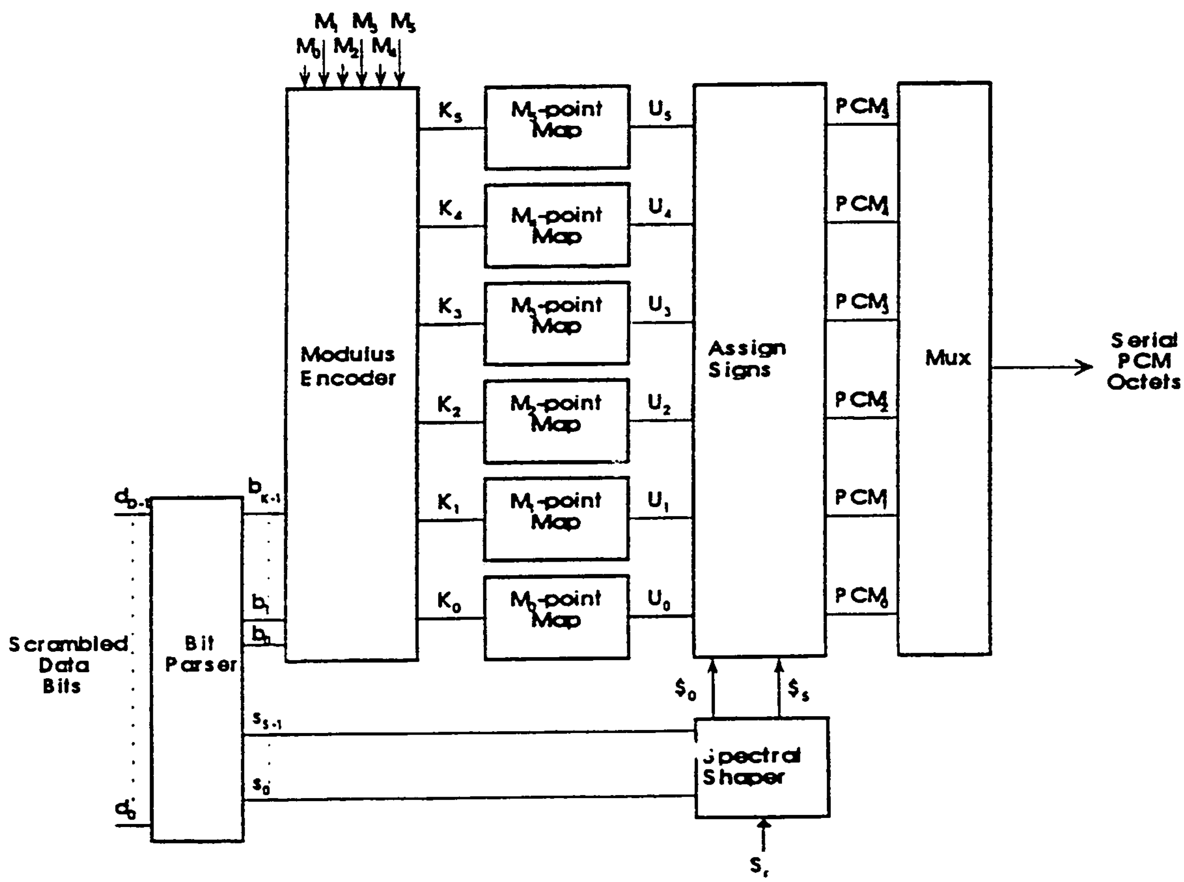

Scrambled Data Bits
Bit Parser
Modulus Encoder
Assign Signs
Mux
Serial PCM Octets
Spectral Shaper
M_0 M_1 M_2 M_3 M_4 M_5
K_5 K_4 K_3 K_2 K_1 K_0
M_5-point Map
M_4-point Map
M_3-point Map
M_2-point Map
M_1-point Map
M_0-point Map
U_5 U_4 U_3 U_2 U_1 U_0
PCM_5 PCM_4 PCM_3 PCM_2 PCM_1 PCM_0
d_{D-1} d_0
b_{K-1} b_1 b_0
s_{S-1} s_0
$\$_0$ $\$_5$
S_r

Figure 4

DD

TENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference ST/61884	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/SG 98/00094	International filing date *(day/month/year)* 14/11/1998	(Earliest) Priority Date *(day/month/year)*
Applicant STMICROELECTRONICS ASIA PACIFIC PTE LTD et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [ ] as suggested by the applicant.
   [X] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
/SG 98/00094

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L25/49

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	INTERNATIONAL TELECOMMUNICATION UNION: "A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN) AT DATA SIGNALLING RATES OF UP TO 56 000 BIT/S DOWNSTREAM AND UP TO 33 600 BIT/S UPSTREAM" ITU-T RECOMMENDATION V.90, September 1998 (1998-09), XP002107773 Geneva, Switzerland page 7, NOTE in paragraph 5.4.5 page 10, paragraph 1 - paragraph 4 ---	1-9
X	WO 98 45970 A (MOTOROLA INC) 15 October 1998 (1998-10-15) page 11, paragraph 1 - paragraph 2 page 12, paragraph 1 page 13, equation 9 ---	1-9
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 July 1999	19/07/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Orozco Roura, C

4

International Application No
/SG 98/00094

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 725 508 A (AT & T CORP) 7 August 1996 (1996-08-07) column 6, line 39 - column 7, line 32; figure 9 ---	1-9
A	EP 0 383 632 A (CODEX CORP) 22 August 1990 (1990-08-22) page 6, line 40 - line 43; figure 1 ---	1-9
A	BIGLIERI E: "HIGH-LEVEL MODULATION AND CODING FOR NONLINEAR SATELLITE CHANNELS" IEEE TRANSACTIONS ON COMMUNICATIONS, vol. COM-32, no. 5, May 1984 (1984-05), pages 616-626, XP000758567 ISSN: 0090-6778 page 617 - page 619, section II -----	1-9

4

INTERNATIONAL SEARCH REPORT

Inf[illegible]tion on patent family members

International Application No

[illegible]/SG 98/00094

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 9845970	A	15-10-1998	AU	6882498 A	30-10-1998
EP 0725508	A	07-08-1996	US	5710790 A	20-01-1998
			CA	2167745 A	02-08-1996
			CN	1143286 A	19-02-1997
			JP	8340358 A	24-12-1996
EP 0383632	A	22-08-1990	AU	630417 B	29-10-1992
			AU	4973090 A	23-08-1990
			CA	2010117 A	16-08-1990
			JP	2246448 A	02-10-1990
			US	5150381 A	22-09-1992

P[illegible]ENT COOPERATION TREA[illegible]

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 21 June 2000 (21.06.00)	
International application No. PCT/SG98/00094	**Applicant's or agent's file reference** ST/61884
International filing date (day/month/year) 14 November 1998 (14.11.98)	**Priority date** (day/month/year)
Applicant PAI, Pratima et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

23 May 2000 (23.05.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer S. Mafla Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

REC'D 09 FEB 2001
WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

3

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
ST/61884		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/SG98/00094	14/11/1998	14/11/1998

International Patent Classification (IPC) or national classification and IPC
H04L25/49

Applicant

STMICROELECTRONICS ASIA PACIFIC PTE LTD et al.

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 8 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
23/05/2000	
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Palacián Lisa, M Telephone No. +49 89 2399 8265

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

4-12	as originally filed			
1-3	as received on	16/11/2000	with letter of	10/11/2000

Claims, No.:

1-9	as received on	16/11/2000	with letter of	10/11/2000

Drawings, sheets:

1/3	as originally filed			
2/3,3/3	as received on	16/11/2000	with letter of	10/11/2000

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:
   ☐ the claims, Nos.:
   ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-9
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-9
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-9
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. The application relates to a method (claim 1) for coding digital data for transmission according to a trellis coding system. The application also discloses the corresponding data encoder (claim 6).

1.1 Such a method and encoder are known from D1 (International Telecommunication Union: 'A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN) AT DATA SIGNALLING RATES OF UP TO 56000 BIT/S DOWNSTREAM AND UP TO 33600 BIT/S UPSTREAM' ITU-T RECOMMENDATION V.90, September 1998, Geneva, Switzerland). D1 discloses a trellis coding system having a predetermined number of states and a predetermined number of state transitions from each state. The data is arranged in a series of frames, a state is associated with each frame to determine a coding strategy for the frame and a look-ahead depth representing a number of frames is selected.

1.2 The problem to be solved is to reduce the computing time and memory requirements of the method.

1.3 The problem is solved by assigning an initial state for a first frame of the series of data frames and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path. Claim 1 further discloses the steps of sequentially fetching data frames in the series and determining their respective states and coding the data frames for transmission according to the coding strategies corresponding to the states assigned.

2. This solution is neither anticipated nor rendered obvious by the disclosure of the documents cited in the International Search Report. D1 discloses the ITU-T Recommendation V.90 for a data encoder in a digital modem using a trellis spectral shaping, it is suggested that an initial state of the shaper can be arbitrarily chosen but without mentioning the initial state assignment for the first frames up to the look-

ahead depth. WO-A-98 45970 also discloses a transmitter for spectrally shaping data signals based on a two-state trellis diagram. The other documents cited in the ISR are less relevant, EP-A-0 725 508 discloses an echo canceller, EP-A-0 383 632 deals with a trellis shaping modulation system in an infinite-dimensional constellation and the article BIGLIERI E: 'HIGH-LEVEL MODULATION AND CODING FOR NONLINEAR SATELLITE CHANNELS' IEEE TRANSACTIONS ON COMMUNICATIONS, vol. COM-32, no. 5, May 1984, pages 616-626 discloses the performance of redundant coding schemes.

3. Claims 1 and 6 meet the requirement of Article 33 PCT.

4. Claims 2-5 and 7-9 are dependent on claims 1 and 6 respectively, and as such also meet the requirements of the PCT with respect to novelty and inventive step.

Re Item VII
Certain defects in the international application

1. Reference signs in parentheses should have been inserted in the claims to increase their intelligibility (Rule 6.2(b) PCT). This applies to both the preamble and characterising portion.

Re Item VIII
Certain observations on the international application

1. Claim 6 relates to a system claim but some of its features ("determines", line 24 and "assigning", lines 28 and 29) comprise method steps. They should have been formulated in terms of the corresponding system features adapted to perform the method features.

METHODS OF EFFICIENT IMPLEMENTATION OF TRELLIS BASED SPECTRAL SHAPING WITH LOOKAHEAD

Field of the Invention

This invention relates to systems an methods for spectral shaping of signals in communications systems, and is particularly applicable to data communication equipment like a modem.

Background of the Invention

In digital communications it is sometimes desirable to avoid transmission at certain frequencies in the transmission spectrum. It is usually necessary to do so in order to avoid undesirable distortion which might result if communications signals use certain frequency components. The presence of such distortion can lead to unnecessary performance degradation.

To avoid transmission at the undesirable frequencies in the spectrum it is necessary to shape the transmission spectrum of the transmitted signals accordingly. The principles of spectral shaping are conveniently described, for example, in United States patent 5,818,879, entitled "Device, System and Method for Spectrally Shaping Transmitted Data Signals". Previously proposed schemes for spectral shaping achieve the desired result by the use of redundancy. One such scheme is the trellis based spectral shaping which has been proposed for the V.90 standard to be ratified by the ITU-T International Telecommunication Union: 'A digital modem and analogue modem pair for use on the public switched telephone network (PSTN) at data signalling rates of up to 56 000 bit/s downstream and up to 33 600 bit/s upstream' ITU-T recommendation V.90, September 1998, Geneva, Switzerland. This scheme uses a convolutional code with two states and provides significant gain.

Summary of the Invention

A straightforward M-ary tree implementation conventionally requires a start-up phase and a

steady-state phase, increasing the complexity. In one aspect of the present invention pre-determined state transitions according to a valid trellis path are assumed during the start-up phase. The performance penalty for small look-ahead depth is insignificant and deviation if present is for a very short duration.

In accordance with the present invention, there is provided a method of coding digital data for transmission according to a trellis coding system having a predetermined number of (N) states and a predetermined number of (M) state transitions from each state, wherein the data is arranged in a series of frames, a state is associated with each frame to determine a coding strategy for the frame, and a look-ahead depth (D) representing a number of data frames is selected, characterised by the step of:

assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path, the method further including:

sequentially fetching subsequent data frames in the series and determining respective states therefor based on a path metric for state transitions computed over the number of frames represented by the look-ahead depth; and

coding the data frames for transmission according to the coding strategies corresponding to the states assigned or determined for the frames, wherein the series of data frames are coded for a shaped spectrum upon transmission thereof.

The present invention also provides a data encoder for generating spectrally shaped coded data according to a trellis coding system, wherein the data is arranged in a series of data frames from a data source and a trellis state is associated with each data frame such that a coding scheme for each frame may be determined on the basis of transitions of states for frames over a selected look-ahead depth (D), comprising:

a buffer memory coupled to the data source for buffering data frames in the series of data frames by the selected look-ahead depth (D);

a metric computation and trellis extension engine coupled to sequentially receive said data frames from the data source and determine node information in a plurality of nodes for each said frame representing possible states, state transitions from a preceding frame and path metrics

for the state transitions;

a current state storage coupled to the metric computation and trellis extension engine for storing the state of a current frame in the series of data frames;

a node memory coupled to the metric computation and trellis extension engine for storing said node information for nodes of a frame succeeding the current frame by the look-ahead depth;

a coding scheme memory for storing a correlation between state transitions and respective coding schemes; and

a processing circuit coupled to the coding scheme memory and metric computation and trellis extension engine for applying a selected coding scheme to a data frame to generate spectrally shaped coded data;

wherein said metric computation and trellis extension engine determines the selected coding scheme for the current frame according to the state stored in the current state storage and a node for the frame succeeding the current frame by the look-ahead depth which is selected on the basis of the path metric for the node, characterised by:

the metric computation and trellis extension engine assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path.

In the preferred for of the present invention, the start-up phase and the steady state are unified. The trellis shaper chooses a predetermined valid trellis path during the start-up phase irrespective of the criterion for selection of the sub-tree. Once in the steady state, it uses the selection criterion to select the state transition.

The trellis shaping function of the preferred embodiment is implemented with a linear structure that requires memory for only the nodes at level D of the binary tree. In the steady state phase, for each input spectral shaper frame X_{i+D} the preferred embodiment computes the path metric associated with each of the M^{D+1} paths. The node at level D+1 which satisfies the selection criterion is then chosen as the best path. The state transition from the current root node and the subsequent root node is determined by the current trellis state and the best path.

The preferred implementation provides a significant reduction in computation and memory

Claims:

1. A method of coding digital data for transmission according to a trellis coding system having a predetermined number of (N) states and a predetermined number of (M) state transitions from each state, wherein the data is arranged in a series of frames, a state is associated with each frame to determine a coding strategy for the frame, and a look-ahead depth (D) representing a number of data frames is selected, characterised by the step of:

assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path, the method further including:

sequentially fetching subsequent data frames in the series and determining respective states therefor based on a path metric for state transitions computed over the number of frames represented by the look-ahead depth; and

coding the data frames for transmission according to the coding strategies corresponding to the states assigned or determined for the frames, wherein the series of data frames are coded for a shaped spectrum upon transmission thereof.

2. A method as claimed in claim 1, wherein fetched data frames are buffered over said look-ahead depth from a current frame X_i to a look-ahead depth frame X_{i+D}.

3. A method as claimed in claim 2, wherein node information for nodes representing possible state transitions at the look-ahead depth are stored in a node memory in an ordered array, and wherein the coding strategy for the current data frame X_i is determined on the basis of a node selected at the look-ahead depth according to said path metric.

4. A method as claimed in claim 3, wherein the node information in said node memory is replaced for each new data frame in the series.

5. A method as claimed in claim 3, wherein the coding strategy for the current data frame X_i is determined according to a state transition from the state associated with said current frame which is determined by a comparison of the position of the node selected at the look-ahead

depth with at least one predetermined threshold.

6. A data encoder for generating spectrally shaped coded data according to a trellis coding system, wherein the data is arranged in a series of data frames from a data source and a trellis state is associated with each data frame such that a coding scheme for each frame may be determined on the basis of transitions of states for frames over a selected look-ahead depth (D), comprising:

a buffer memory coupled to the data source for buffering data frames in the series of data frames by the selected look-ahead depth (D);

a metric computation and trellis extension engine coupled to sequentially receive said data frames from the data source and determine node information in a plurality of nodes for each said frame representing possible states, state transitions from a preceding frame and path metrics for the state transitions;

a current state storage coupled to the metric computation and trellis extension engine for storing the state of a current frame in the series of data frames;

a node memory coupled to the metric computation and trellis extension engine for storing said node information for nodes of a frame succeeding the current frame by the look-ahead depth;

a coding scheme memory for storing a correlation between state transitions and respective coding schemes; and

a processing circuit coupled to the coding scheme memory and metric computation and trellis extension engine for applying a selected coding scheme to a data frame to generate spectrally shaped coded data;

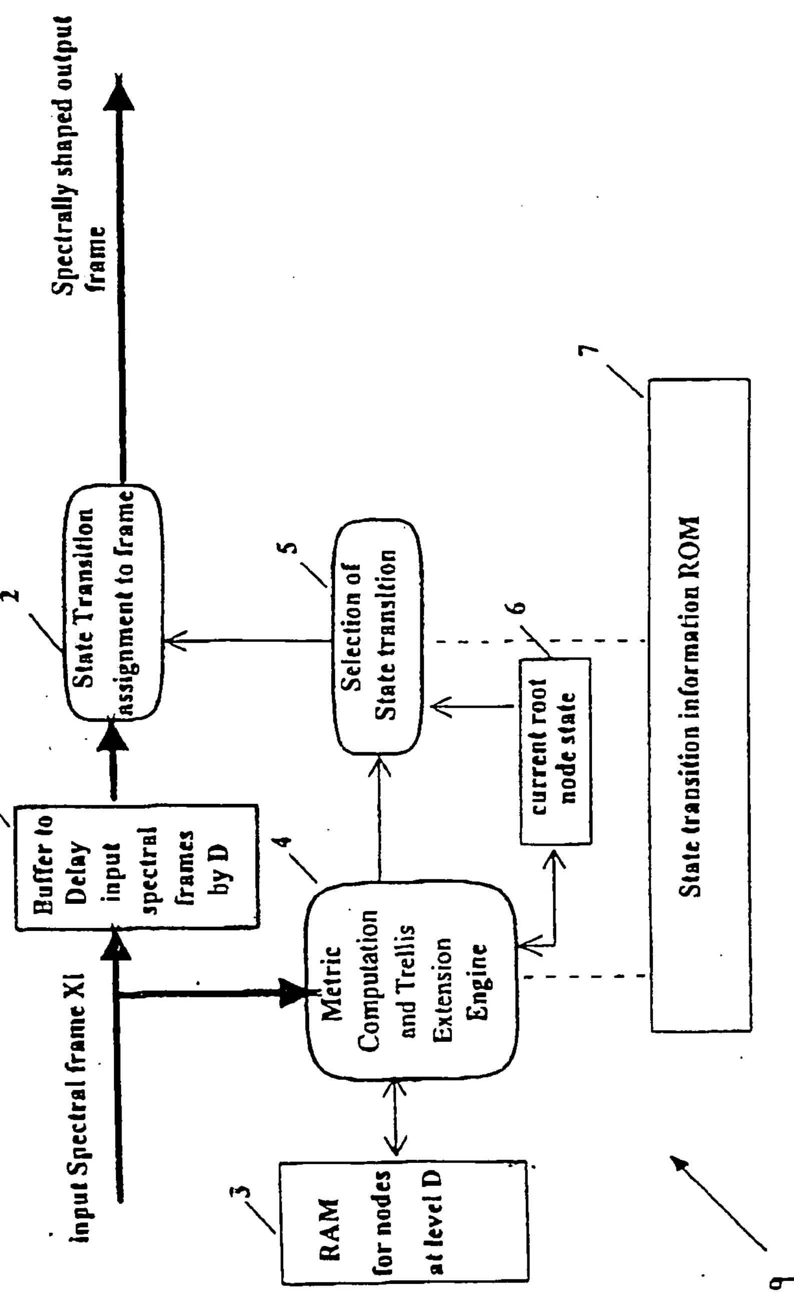
wherein said metric computation and trellis extension engine determines the selected coding scheme for the current frame according to the state stored in the current state storage and a node for the frame succeeding the current frame by the look-ahead depth which is selected on the basis of the path metric for the node, characterised by:

the metric computation and trellis extension engine assigning an initial state for a first frame of the series of data frames, and assigning states for the subsequent data frames in the series of data frames up to the look-ahead depth according to a predetermined valid trellis path.

7. An encoder as claimed in claim 6 wherein, for the first frames within the look-ahead depth of the series of data frames, states and state transitions are assigned according to a predetermined valid trellis path.

8. An encoder as claimed in claim 6 or 7, wherein for each said data frame received by the metric computation and trellis extension engine the node information in the node memory is replaced with new node information representing the received data frame and the possible state transitions from the preceding data frame.

9. An encoder as claimed in claim 8, wherein the node information for the nodes is stored in linear array in said node memory, and wherein the coding scheme for the current frame is determined according to the position of the selected node within the node memory linear array.


Input Spectral frame Xi
1
Buffer to Delay input spectral frames by D
2
State Transition assignment to frame
Spectrally shaped output frame
3
RAM for nodes at level D
4
Metric Computation and Trellis Extension Engine
5
Selection of State transition
6
current root node state
7
State transition information ROM
9

Fig(3)

ST/61884

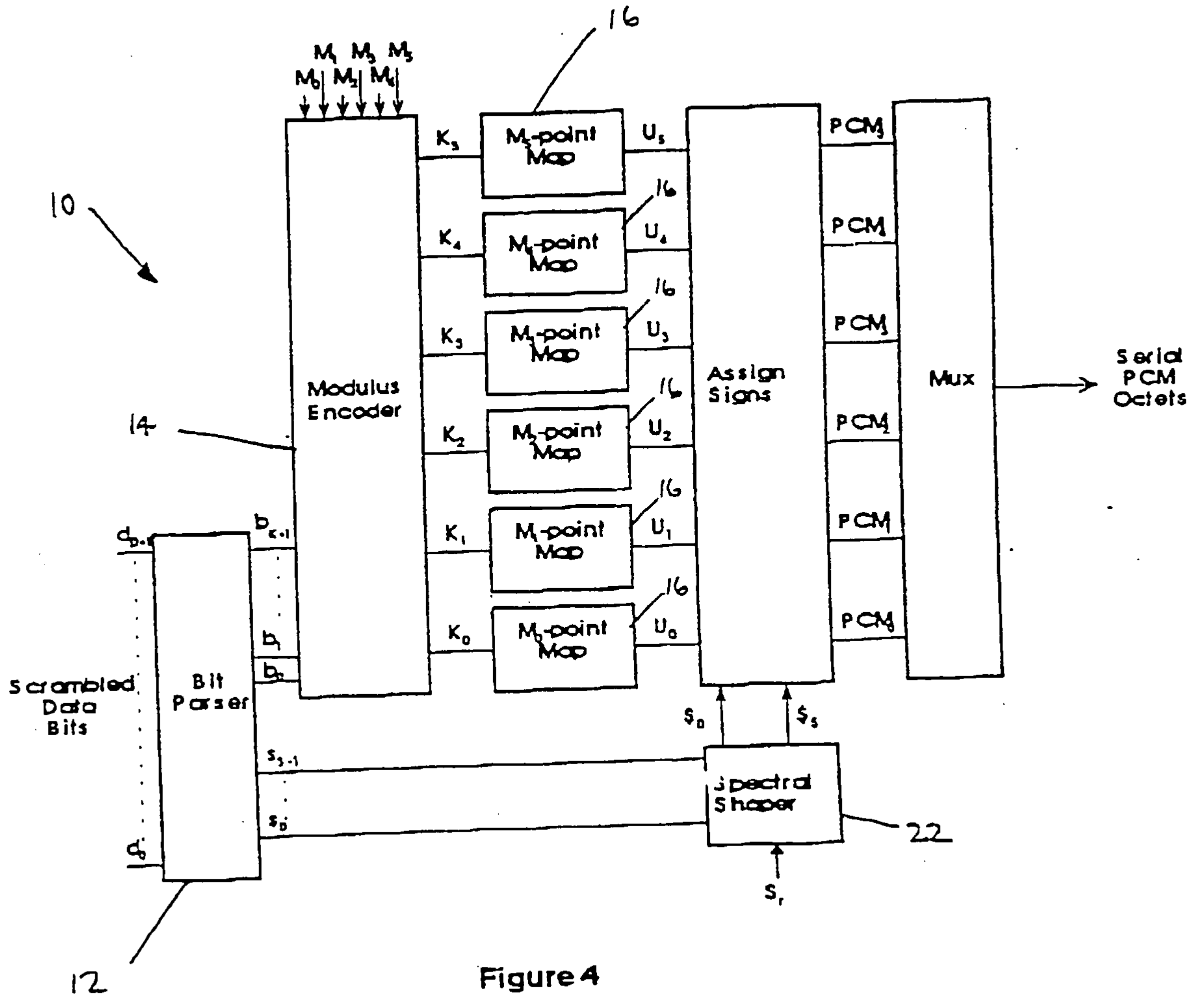


Figure 4